Chaos and Complexity Letters
Volume 2, Number 2/3, pp. 189-211
ISSN 1555-3995

PROCESSING OF POSITIVE VERSUS NEGATIVE EMOTIONAL WORDS IS INCORPORATED IN ANTERIOR VERSUS POSTERIOR BRAIN AREAS: AN ERP MICROSTATE LORETA STUDY

Lorena R.R. Gianotti*, Pascal L. Faber, Roberto D. Pascual-Marqui, Kieko Kochi and Dietrich Lehmann
The KEY Institute for Brain-Mind Research, University Hospital of Psychiatry, Zurich, Switzerland

Abstract

The spatio-temporal organization of the neural activity that underlies perception of emotional valence was studied analyzing 33-channel event-related potential maps (ERP maps) from 21 normals while reading a sequence of emotional positive, negative and neutral words; subjects were asked to repeat the last word if a question mark followed; they were not informed that the study concerned emotions. Brain electric activity to emotional positive and negative words was compared. Microstate segmentation of the 113 ERP maps (corresponding to the 448 ms of word presentation) identified 14 microstates, i.e. putative steps of information processing. Three microstates, #4 (90-122 ms), #7 (178-202 ms) and #9 (242-274 ms) showed global map topography differences between emotional positive and negative words. During these three microstates, the involved brain areas were identified using Low Resolution Electromagnetic Tomography (LORETA). The results showed that the extraction of valence during the three emotion-sensitive microstates was incorporated in different brain areas: positive as well as negative emotional words caused predominant left-hemispheric activation in #4 and #9, but predominant right-hemispheric activation in #7. The striking communality across the three microstates however was that in each of them, positive words compared to negative words clearly evoked significantly more anterior brain activity.

1. Introduction

Detecting emotionally salient cues in the environment is a fundamental skill that readies the organism for successful behavior [Damasio, 1999]. But, to be useful, detection of potentially salient cues of emotional valence (positive and/or negative) must be appropriate, automated, and rapid so that valence is assessed within useful time.

* E-mail address: lgianott@key.unizh.ch, Tel: +41-44-388-4939, FAX: +41-44-380-3043. Address of correspondence: Dr. Lorena R.R. Gianotti, The KEY Institute for Brain-Mind Research, University Hospital of Psychiatry, Lenggstrasse 31, CH-8032 Zurich, Switzerland

1.1. Temporal Aspects of Emotional Processing

The speed of valence processing for successful, real time interactions with the surround must be high, in fractions of seconds. Analysis of brain electric or magnetic measurements at present are the only approaches that offer the required time resolution and thereby make it possible to describe physiological correlates of very rapid processing. Indeed, in the last years, using brain electric and magnetic data analyzed with various techniques, many studies demonstrated that emotional stimuli are perceived and differentiated within the first 140 ms after stimulus onset [e.g., Esslen et al., 2004; Ortigue et al., 2004; Pizzagalli et al., 2002; Pourtois et al., 2004; Skrandies, 1998; Skrandies & Chiu, 2003]. As early as in 1979, valence effects have been reported in a reading study with event-related potential (ERP) waveshapes at about 140 ms after onset of word presentation [Begleiter et al., 1979], but this study was neglected until recently.

ERP studies in all sensory modalities have shown repeatedly that within fractions of seconds, different processing steps follow each other and are putative "components" of the ERPs. In other words, processing of the incoming information is certainly not a homogenous activity over time, but successive sub-processes or steps are distinguishable. However, scalp-recorded ERP waveshapes depend on the chosen reference (including recalculations to current source density) and therefore, conventional component latencies of ERP waveshapes are ambiguous.

The present study utilized ERP microstate analysis to examine the temporal development of brain information processing. Microstate analysis assesses differences in spatial configuration of the multichannel ERP scalp fields instead of differences in ERP waveshapes at individual electrode positions: the ERP recordings can be viewed as a series of instantaneous maps in a millisecond-by-millisecond rendering of the brain electric field on the scalp. The potential landscapes of these instantaneous maps vary over time in a non-steady manner; they tend to remain quasi-stable for brief, fraction of second-periods, the (global) microstates, that are concatenated by relatively rapid changes of potential landscape [Lehmann & Skrandies, 1980]. Because different brain potential landscapes on the scalp must have been generated by differently active neuronal generator populations, and because it appears reasonable to assume that different active neuronal generator populations implement different functions, different microstates were conceptualized to reflect different functional steps in the stream of information processing [Lehmann, 1987; Lehmann et al., 1998]. Indeed, various studies showed that the topography, sequence and duration of ERP microstates were shown to reflect steps and types of information processing [e.g., Brandeis et al., 1995; Koenig et al., 1998; Michel et al., 2004]. Thus, the analysis approach permits to identify steps of brain information processing. Brain information processing is known to be massively parallel; hence, each microstate taking into account the entire brain electric field consists of very many parallel local states. At the onset of a new microstate, the set of local states must have undergone some change: there might be at least one additional or omitted local state, or at least one of the local states may have become stronger or weaker. Also, there could well be some local states that continued across two or more microstates.

The identified microstates can be tested for differences between stimulus conditions. Those microstates that differ in potential landscape between conditions then can be analyzed as to the intracerebral localization of the activity.

1.2. Localization of Emotional Processing in the Brain

The issue of localizing emotional processing in the brain has attracted attention for many years. Frequently discussed are two global models about the spatial organization of brain activity during emotional processing: the 'valence hypothesis of hemispheric specialization' and the 'right hemispheric dominance model'. The first model posits that emotion processing is lateralized, with positive (or approach-related) emotions in the left, and negative (or withdrawal-related) emotions in the right hemisphere, often specifically in fronto-temporal regions. It is based on clinical data [e.g., Carota et al., 2001; Gainotti, 1972; Terzian & Ceccotto, 1959], EEG [e.g., Aftanas et al., 2001; Davidson et al., 1990; Graham & Cabeza, 2001], and functional imaging [Canli et al., 1998; Sutton et al., 1997]. However, many recent studies did not support this model [e.g. Cato et al., 2004; Fossati et al., 2003; Sander et al., 2003; Schupp et al., 2004]. The second model, right hemispheric dominance, posits that emotional processing is done in the right hemisphere [e.g., Borod et al., 1992; Spence et al., 1996]. Also in regard to this second model, several studies failed to support an exclusive right lateralization of emotion [e.g., Cato et al., 2004; Sander et al., 2003]. A quantitative meta-analysis of 65 neuroimaging studies on emotions [Wager et al., 2003] found no support for the right hemispheric dominance model, and limited support for the valence hypothesis model.

A methodological caveat: Conventional localization in ERP work accepts the location of the waveshape of largest amplitude (or of the maximal or minimal value in a potential map) as source localizer, but the source is not necessarily perpendicular under the recording site of the largest potential, because electric sources have orientations. Recalculation of the scalp-measured values to average reference or current source densities does not solve the problem. Intracerebral source modeling is needed.

Contemporary studies of emotional processing project a very differentiated view of the brain areas involved in the various studied functions such as perception, experience, and expression of emotions, with an overwhelming amount of localization details, often in a bewildering variety of brain areas, and with a great richness of different experimental designs from viewing of emotional images to willful, self-implementation of emotions, and using several basically different techniques for physiological measurements (PET, fMRI, Infrared-mapping, MEG, EEG, ERP) and within each of them, large and diversified arsenals of analysis methods. It appears that a global perspective is desirable to systematize principle rules of brain information processing of emotional valence.

In the present study that used ERP field data as measurements and microstate analysis in order to identify the rapid steps of emotional processing, localization of the involved brain areas was done with Low Resolution Electromagnetic Tomography (LORETA, [Pascual-Marqui et al., 1999; Pascual-Marqui et al., 1994]). LORETA is an inverse solution method that estimates the putative neural sources of electrical brain activity recorded at the level of the scalp. LORETA was applied to those ERP microstates that differed in scalp-recorded field topography between positive and negative words.

1.3. The Present Study

In sum, the aim of the present study was to examine the temporal and spatial organization of neuronal networks that process valence information during reading. ERP electric field data recorded during reading of emotional positive and negative words were analyzed using microstate analysis and LORETA functional tomography. We hypothesized that there are different steps of emotional processing that occur rapidly within fractions of seconds, and that assessment of emotional valence is incorporated by activity of neural assemblies with different spatial organization. Lateralized or non-lateralized valence effects were not additionally hypothesized, given the many inconsistencies in the published literature.

2. Materials and Methods

2.1. Subjects

Subjects were 21 right-handed German or Swiss-German native speakers (mean age 23±3 years, 13 women), recruited among first-year psychology students at Zurich University, and remunerated with CHF 40. None of them had any history of psychiatric or neurological disorders, or alcohol or drug abuse. The study was approved by the Ethics Committee of the University Hospital Zurich, and subjects gave their written, informed consent for participation.

2.2. Stimuli

27 emotional positive and 27 emotional negative words, together with 20 neutral words were used as stimuli, using a word list [Esslen, 1997] that was developed as follows: 116 pre-selected words were rated by 15 subjects for their emotional valence on a 1-7 scale (1=very negative; 7=very positive). The 27 most negative, the 27 most positive, and the 20 most neutral words constituted the three stimulus classes, making sure that there was no significant difference in word length (ranges were 3-6 letters and 1-3 syllables), frequency of occurrence in German texts (list F in [Rosengren, 1977]) and subjective rating of imagery propensity between the positive and the negative word classes.

The semantic characteristics [Osgood, 1952] of ‘potency’ (weak-strong) and ‘activity’ (passive-active) were rated by 20 independent volunteers on a 1-7 scale. Valence of the utilized words was re-rated by the present subjects after the experiment. The list of the German stimulus words with their English translations is available upon request. The neutral word class was not used for the present analysis.

2.3. Procedure

Subjects were seated in a comfortable chair in a sound, light, and electrically shielded EEG recording chamber. The experimenter in the adjacent recording room was in contact with the subject via intercom. During recording, the subject’s head was placed in a forehead-chin rest

so that the distance between eyes and PC screen was constant (100 cm) and head movements were minimized.

Stimuli were presented using the software ERTS (BeriSoft Cooperation, Frankfurt, Germany). Words extending in a 3.7 (±0.7) degree visual angle were sequentially presented for 450 ms each at the center of a PC screen at intervals of 2000 ms. During the interval, a fixation cross was displayed at the screen center.

The 74 words were used repeatedly as stimuli, in 8 runs, for a total of 596 word presentations for each subject. In order to maintain some surprise in stimulus appearance while limiting the persistence of a given emotion, we chose a pseudo-random sequence of presentation where no more than 2 successive stimuli of the same class followed each other. For each subject and for each run, different pseudo-random sequences of the 74 words were used. Seventeen additional stimuli, inserted at random, were question marks. Words, fixation points and question marks were displayed in white on a dark grey background. Between runs, there was a 1 minute intermission. The entire recording lasted about 27 minutes.

2.4. Subject Instruction

The subjects were instructed to fixate the cross at the center of the screen, and to read the words silently but attentively. When the question mark appeared, the subject had to repeat loudly the last word that was presented before the question mark (recall task).

After the EEG recording, the subjects were asked to judge the emotional valence of all 74 stimulus words on a 1-7 scale from ‘very negative’ (‘1’) to ‘very positive’ (‘7’) as above.

2.5. ERP Recording and Computation

GRASS cup electrodes were placed according to the 10/10 international system [Nuwer et al., 1998] at the 33 positions Fp1/2, Fpz, AF3/4, F7/8, F3/4, Fz, FC5/6, FC1/2, T7/8, C3/4, Cz, CP5/6, CP1/2, P7/8, P3/4, Pz, PO3/4, O1/2 and Oz, with Cz as recording reference. Horizontal and vertical eye movements were recorded with electrodes at the outer left and right canthi and a left infraorbital electrode. Impedances were kept below 10 kOhm. The signals were amplified (bandpass 0.5-70 Hz) and digitized (250 samples/s) using a 64-channel EEG/ERP system (hardware: M & I Ltd., Prague, Czech Republic; software: Easys221, Neuroscience Technology Research Ltd., Prague, Czech Republic).

Off line, all data epochs, starting at the onset of word presentation up to 113 timeframes later (=448 ms), thus covering the entire word presentation from onset to offset, were carefully examined on a computer display for artifacts (muscle, eye and head movement) before averaging. The mean number of artifact-free data epochs across subjects that were eventually available did not differ significantly between word classes (positive: mean=130.4, S.D.=43.1, negative: mean=129.1, S.D.=40.4).

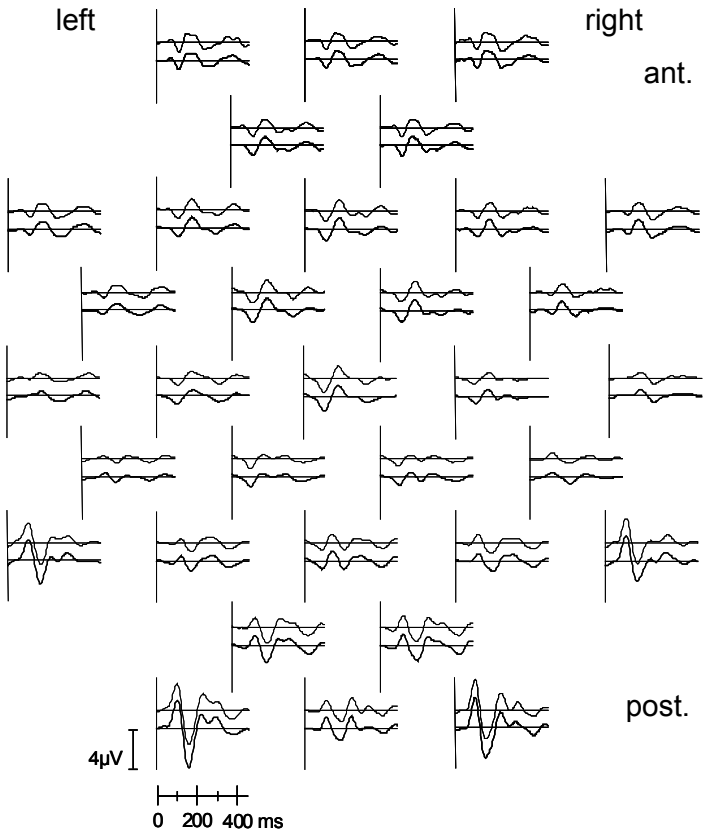

Figure 1. 33-channel grandmean ERP waveshapes (across 21 subjects) for positive (thin traces) and negative (heavy traces) emotion words; the zero microVolt levels are offset for ease of visualisation of the corresponding waveshapes. Head seen from above, nose up, left ear left; waveshapes are localized in a semi-schematic electrode array where the electrode locations were a subset of the 10/10 locations (see methods).

For each subject, all available data epochs were averaged separately for the two word classes, and the resulting, average ERPs were digitally band passed (2-20 Hz) and recomputed against average reference. Grandmean 33-channel ERP waveshapes across all 21 subjects separately for the two word classes were computed and are shown in Figure 1 as overview of the data. In order to normalize the data, Global Field Power (GFP, [Lehmann & Skrandies, 1980]) for each given timeframe (map) was set to 1 by dividing the voltages at all electrodes by the GFP value of that map. GFP yields a single time series for all channels; as used in this study, GFP is equivalent to the spatial standard deviation of the instantaneous voltages at all electrodes of a given map.

Grand-grandmean 33-channel ERP waveshapes were computed across the two word classes and the 21 subjects, and were transformed into a series of momentary ERP maps that display the potential distribution landscapes of the 113 timeframes (Figure 2).

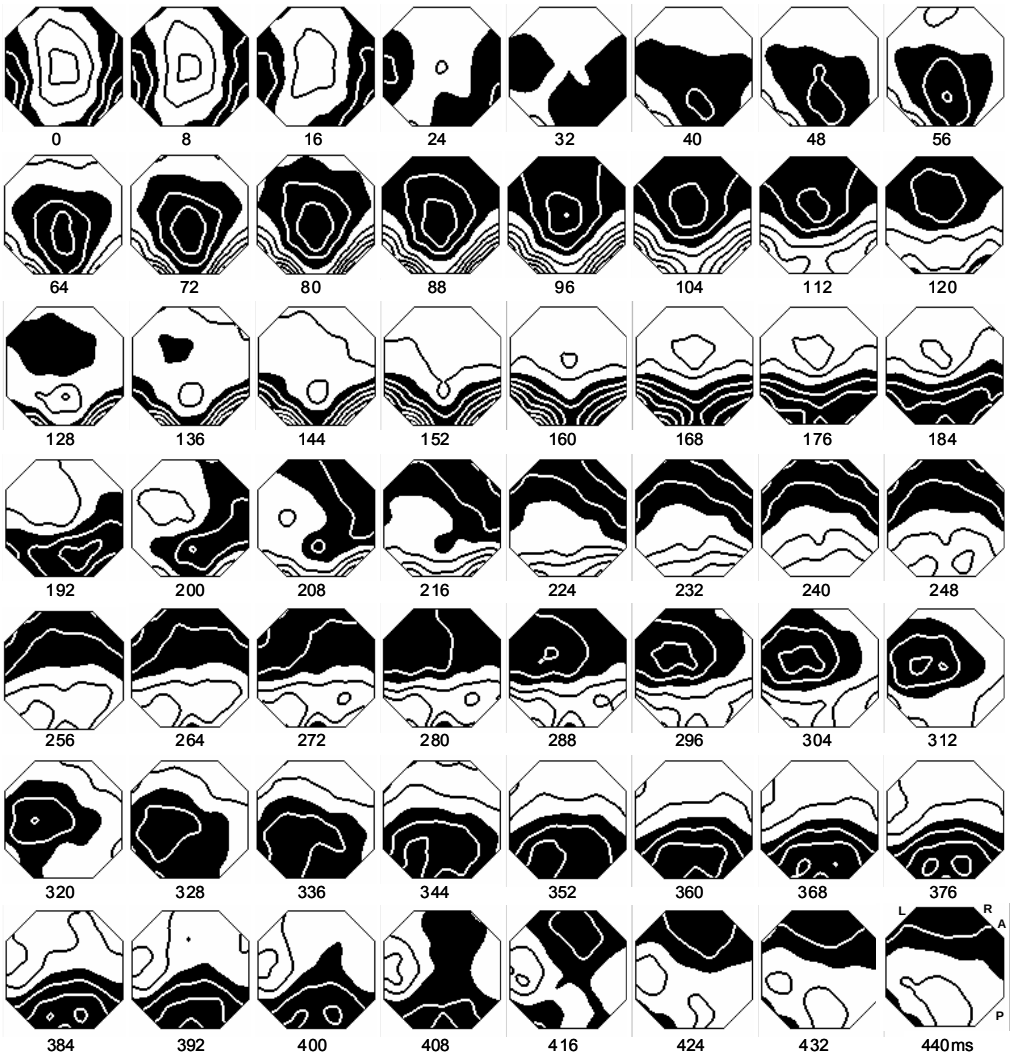

Figure 2. The 33-channel ERP grand-grandmean map series (56 maps at 8 ms intervals) across the 2 word classes and 21 subjects. Head seen from above, nose up, left ear left; L/R = left/right, A/P = anterior/posterior. Isopotential level in arbitrary units. White=positive, black=negative potential versus average reference. Latencies in ms after stimulus onset.

2.6. Analysis

2.6.1. Microstate Analysis

The grand-grandmean ERP map series was parsed into temporal microstates defined as brief sequences of successive ERP maps with quasi-stable potential landscape [Lehmann & Skrandies, 1980] using the global clustering approach [Pascual-Marqui et al., 1995]. The settings for this microstate analysis were: 20 random initializations with maximal 50 iterations, permitting between 2 and 12 clusters disregarding polarity. Based on the Global Map Dissimilarity (GMD, [Lehmann & Skrandies, 1980]), which is a global measure of

'landscape distance' between two maps, each ERP map was assigned to one of the obtained clusters. A microstate is defined as a sequence of successive ERP maps that are assigned to the same cluster. Every time an ERP map is assigned to a new cluster (or to the same cluster but with reversed polarity), a new microstate starts. Note that each of these clusters could occur several times with the same or opposite polarity during the analysis period.

The microstate analysis was rerun 10 times. Because of the limited, even though randomly selected number of initializations and because of the limited iterations, in repeated runs of the analysis program, a certain variance of the timeframes that start new microstates ('start frames') is to be expected. In order to identify the most consistent start frames across the repeated analysis runs, their occurrence probability was tested.

For each run, each of the 113 frames was assigned the value 1 if it was a start frame, and the value zero if not. In order to give equal weight to all runs regardless of the number of start frames in a given run, these assigned values of 1 or zero were normalized for each run using formula 1:

$$wV_i = \frac{V_i}{\sum_{i=1}^{113} V_i} \qquad \text{(formula 1)}$$

where wV_i is the normalized value at the timeframe i, V_i is the original value at the timeframe i.

Thus, 10 series were obtained, each consisting of 113 wV_i –values (one for each timeframe). For each timeframe, the significance across the 10 runs of the deviation of the normalized values from zero was tested using t-statistics (n=10). Timeframes yielding *P*-values <0.1 were accepted as start frames.

After identification of the start frames, thereby of the start latency of the microstates, the grand-grandmean ERP maps were averaged within each microstate. For statistical comparison of the microstates between the word classes, the individual subjects' momentary, GFP-normalized ERP maps were averaged within each microstate, as separate 'microstate maps' for the two word classes.

2.6.2. Global Differences between Microstate Maps for Positive and Negative Emotions

As omnibus test for global differences of the microstate maps between the two conditions, all possible univariate *t*-tests were computed (33 electrodes x number of microstates) and the significant threshold was determined by the non-parametric randomization method [Nichols & Holmes, 2002] that corrects for multiple testing.

For each microstate, the difference in global map landscape between maps evoked by positive and by negative emotional words was tested, using topographic analysis of variance (TANOVA). TANOVA employs the GMD and a statistical randomization procedure to establish the exact probability of the observed 'distance' [Pitman, 1937], with additional correction for multiple testing (see [Strik et al., 1998]).

A landscape difference between two scalp potential maps must have been caused by a different spatial distribution of neuronal activity [Fender, 1987]. Source localization analysis has to identify the involved brain areas. The microstates where TANOVA showed global ERP

map differences at $P<0.1$ between emotionally positive and negative words were further analyzed using source localization.

2.6.3. Intracortical Source Localization Using LORETA

The three-dimensional, intracortical distribution of the active sources that gave rise to the topography of electric potential on the scalp when reading the emotional positive and negative words was computed using Low Resolution Electromagnetic Tomography (LORETA, [Pascual-Marqui et al., 1999; Pascual-Marqui et al., 1994]). LORETA computes, from the scalp recorded voltages, the three dimensional distribution of the electrically active neuronal generators in the brain as current density values (A/m2) for each voxel. The version of LORETA in the present study used a three-shell spherical head model registered to the digitized Talairach and Tournoux [Talairach & Tournoux, 1988] atlas. Electrode coordinates were calculated by cross-registration between spherical and realistic head geometry following [Towle et al., 1993]. Computations were restricted to cortical gray matter according to the digitized Probability Brain Atlas (Brain Imaging Centre, Montreal Neurological Institute, 2394 voxels). In the current implementation, a spatial resolution of 7 mm was used.

For each subject, LORETA images were computed separately from the average ERP maps for positive and for negative emotional words, for each of the identified microstates for which TANOVA had reached $P<0.1$. For each microstate, paired voxel-by-voxel *t*-tests across subjects were calculated, in order to assess the spatial distribution of activity elicited by the positive and negative emotional words. Statistical results were assessed non-parametrically with a randomization test [Nichols & Holmes, 2002] that corrects for multiple testing.

All voxels at corrected *t*-test $P<0.10$ were accepted as voxels of interest (VOI), and used for further analysis. For each microstate and both conditions, a 3-D center of gravity (and its 95% confidence area) was computed as average location of all participating VOI.

3. Results

3.1. Recall Task

All subjects gave 100% correct answers after the 17 times in random order appearance of the question marks. The perfect accomplishment of the recall task ensured us that all subjects were paying attention to the words, through the whole experiment.

3.2. Rating of Semantic Characteristics

The rating of emotional valence of the positive and negative words across subjects differed significantly (positive words: mean=6.07, S.D.=0.29; negative words: mean= 2.05, S.D.=0.34, df=20, t=35.23, paired *t*-test $P<0.0001$). The present rating correlated very significantly with the previous rating of the same words by independent subjects ([Esslen, 1997]: r=0.980, df=72, $P<0.0001$).

Concerning the two other characteristics of ‘potency’ and ‘activity’ [Osgood, 1952], no difference was found for ‘potency’ (positive words: mean=5.15, S.D.=1.44; negative words:

mean= 4.81, S.D.=1.81). But a significant difference appeared for 'activity' as rated by the group of 12 independent volunteers: Positive words were rated as more active than negative words (positive words: mean=5.00, S.D.=0.65; negative words: mean=4.09, S.D.=0.69, df=11, paired *t*-test t=3.51, *P*<0.005).

3.3. ERP Results

3.3.1. Microstate Analysis

Across the 10 microstate analysis runs, between 6 and 8 clusters were observed. The t-statistic that was applied to identify the start frames over the 10 analysis runs recognized 13 timeframes as start frames (Figure 3), thereby establishing 14 sequential microstates. The start and end points of the microstates (the microstate borders) in milliseconds latency were set between the latency of the timeframe that preceded the start frame and the latency of the start frame. The topography, latency, and duration of these 14 microstates are summarized in Figure 4A,B. The mean duration of all microstates was 32 ms (range=20-52 ms, S.D.=8.6). The 14 microstate maps for the two word classes, averaged across subjects, are illustrated in Figure 4C.

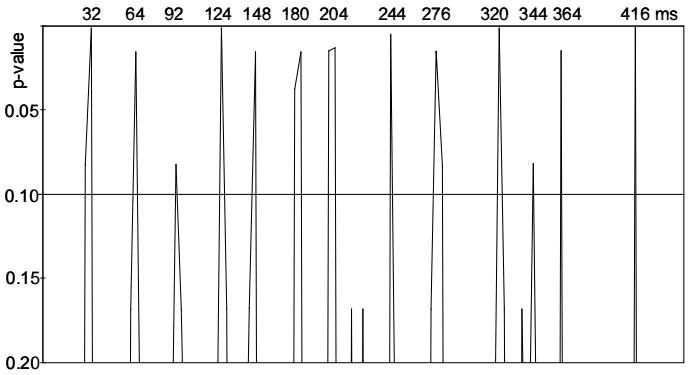

Figure 3. Identification of timeframes as start frames of new microstates. Vertical: *P*-values of the *t*-statistic that combined the 10 microstate analysis runs. Thirteen timeframes reached *P*<0.1 as start frames of new microstates, at the latencies (horizontal) listed on top.

3.3.2. Global Differences Between Microstate Maps for Positive and Negative Emotions

The omnibus test that included the 462 univariate *t*-tests (33 electrodes x 14 microstates) with correction for multiple testing showed a significant difference at *P*=0.002 between the microstate maps for the two conditions of emotional positive and negative words.

The TANOVA tests for global, topographic differences between the landscapes of the 14 microstate maps for emotional positive words and the corresponding 14 microstate maps for emotional negative words yielded relevant results at *P*<0.10 for three microstates, microstate #4 (90-122ms, *P*<0.002), #7 (178-202 ms, *P*<0.007), and #9 (242-274 ms, *P*<0.09).

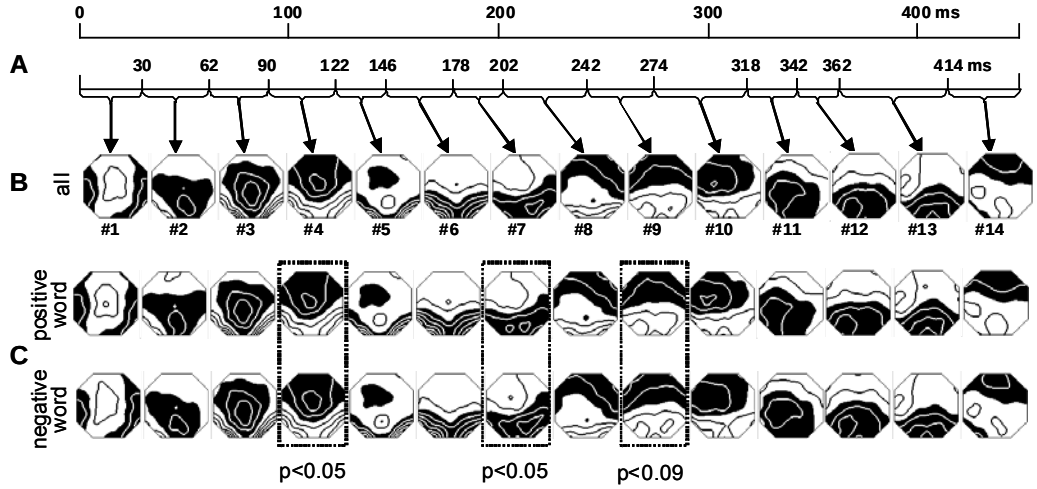

Figure 4. (A) Latencies, and (B) topographies of the 14 microstates of the grand-grandmean map series. (C) the 14 grandmean microstate maps (separate averages for emotional positive and negative words). Microstates #4, #7 and #9 differed in global map topography between the two word classes (*P*-values indicated). Head seen from above, nose up, left ear left; isopotential levels in arbitrary units; white=positive, black=negative potential versus average reference.

The topography (Figure 4C) of the first of these three microstates, microstate #4, showed the typical topography of the P100 component with positive polarity in occipital and temporal areas and negative polarity in central and frontal areas. The second microstate (#7) was characterized by positive polarity in frontal regions (slightly lateralized to the left hemisphere) and negative polarity in temporal and occipital regions (slightly lateralized to the right hemisphere). The third microstate (#9) showed a positive polarity in central and occipital regions, and a negative polarity in frontal regions.

3.3.3. Intracortical Source Localization Using LORETA

For the three relevant microstates, the voxel-by-voxel paired *t*-statistics (N=21) between the subjects' LORETA images for emotional positive *versus* emotional negative words after correction for multiple testing yielded 556 voxels at $P<0.10$ (voxels of interest, VOI). The VOI are displayed for the three microstates in Figure 5 in glass brain views, and in Figure 6 in external and mesial views of the cortical surface.

Examination of Figure 5 and 6 shows that negative emotional words compared with positive ones involved a larger number of VOI in microstate #4 and #9, and only barely missed this preponderance in microstate #7. Table 1 specifies that in #4, 72% of 135 VOI carried negative valence, and in #9, 89% of 182 VOI. In microstate #7, the negative valence cases still reached 45% of the 239 VOI.

Examination of Figure 5 and 6 further shows that the spatial pattern of VOI is different in all three microstates. Table 1 reports the detailed VOI incidences for each microstate and both hemispheres and valences. Closer scrutiny reveals two noteworthy characteristics that are particularly evident in the display of the VOI gravity centers and their 95% confidence borders in Figure 7.

(1) The distribution of the VOI in each of the three microstates was clearly lateralized; moreover, within the three microstates positive as well as negative-valence VOI were lateralized in the same hemisphere. However, these clear hemispheric lateralizations were not the same in the three microstates. In microstate #4 and #9, most of the VOI for both valences were in the left hemisphere, but in microstate #7, most were right for both valences. Figure 7 illustrates these lateralizations by the 95% confidence borders that are far away from the brain midline.

(2) In all three microstates, the VOI for positive emotion were more anterior than the VOI for negative emotion, as obvious in Figure 7 where the 95% confidence borders of the VOI gravity center locations for positive and for negative emotional words were separated by wide anterior-posterior distances in all three microstates.

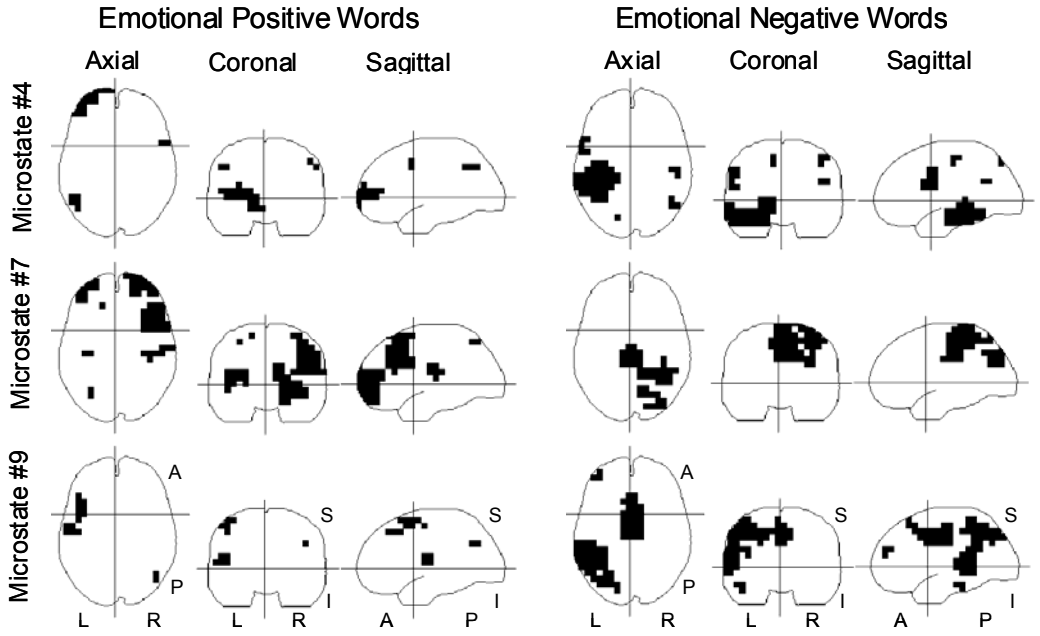

Figure 5. Voxels of interest of the LORETA-based statistical nonparametric maps (SnPM) activated during emotional positive words (left) and emotional negative words (right) in the three microstates #4, #7, and #9, displayed in SPM 'glass brain' space as axial, coronal, and sagittal views. L/R = left/right, A/P = anterior/posterior, S/I = superior/inferior.

3.3.3.1. Brodmann Areas (BAs)

For the following overview, we selected from Table 1 those BAs that contained 10 or more VOI for positive or negative emotions, in the left or in the right hemisphere, in one of the three microstates as 'BAs of interest'. These BAs of interest are listed in Table 2 with their anatomical brain regions.

Microstate #4: For emotional positive words, BA 10 (left superior, middle, and inferior frontal gyrus) was the sole BA of interest. Emotional negative words showed stronger activation than positive words in three BAs of interest (BA 20, 36, 37), in left middle and inferior temporal gyrus, left fusiform gyrus, and left parahippocampal gyrus.

Microstate #7: For emotional positive words, in the left hemisphere, BA 10 was the only BA of interest (left superior, middle and inferior frontal gyrus). In the right hemisphere, the BAs of interest (right BA 8, 9, 10, 11) were right superior, middle and inferior frontal and precentral gyrus. Emotional negative words showed stronger activation than positive words in the left hemisphere in one BA of interest (BA 31: left paracentral lobule and cingulate gyrus). In the right hemisphere, the four BAs of interest (BA 7, 19, 31, 40) involved right middle temporal and postcentral gyrus, paracentral lobule, superior and inferior parietal lobule, precuneus and cuneus, cingulate gyrus, and middle and superior occipital gyrus.

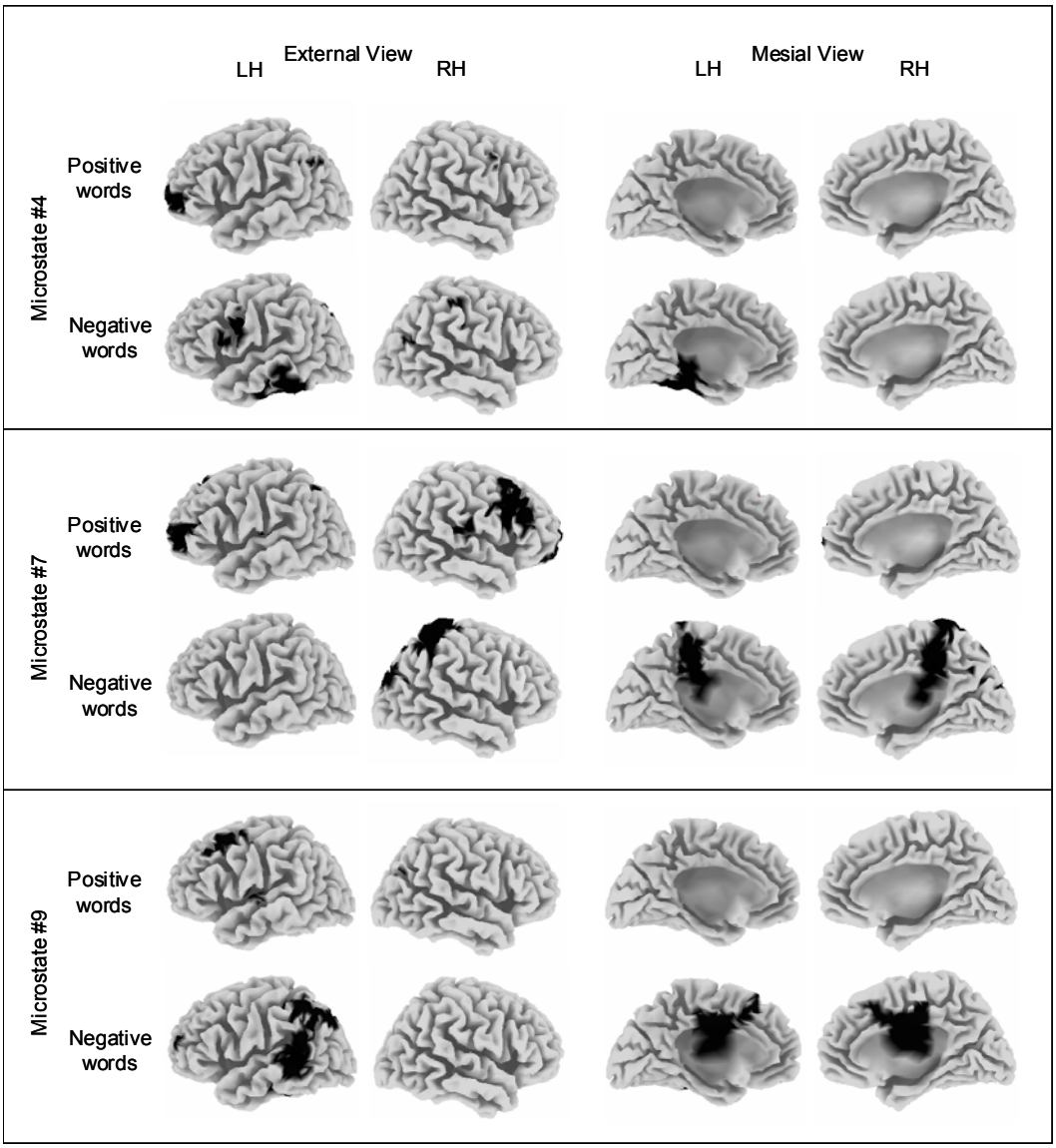

Figure 6. Voxels of interest (black) of the LORETA-based statistical nonparametric maps (SnPM) activated during emotional positive words and emotional negative words in the three microstates #4, #7, and #9. Results are displayed on the 'fiducial cortical surface' (boundary midway through cortical thickness, Dickson et al., 2001). LH/RH = left/right hemisphere.

Microstate #9: For emotional positive words, the most prominent BAs (listed as BA of interest) actually contained only five voxels (25% of all 20 voxels at $P<0.1$). This single BA of interest was in left middle frontal and precentral gyrus (BA 6). Emotional negative words showed stronger activation than positive words in six BAs of interest, five of them in the left hemisphere: BA 19, 21, 22, 24, 40, in left inferior parietal lobule, precuneus, and superior and middle temporal, supramarginal, and cingulate gyri. The sixth BA of interest was on the right side, BA 24 in cingulate gyrus.

Table 1. LORETA voxels during the three microstates for emotional positive and negative words.

	Emotional Positive Words						Emotional Negative Words					
Microstate:	#4		#7		#9		#4		#7		#9	
BA#	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH
1	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	2	-	1	-	-
3	-	-	-	1	-	-	-	1	-	-	-	-
4	-	-	-	-	1	-	2	-	2	2	-	-
5	-	-	-	-	-	-	-	-	2	9	-	-
6	-	2	-	5	5	-	8	-	3	3	-	-
7	-	-	2	-	-	-	2	-	1	18	10	-
8	-	-	1	10	4	-	-	-	-	-	3	2
9	-	-	-	23	1	-	-	-	-	-	-	-
10	23	-	21	19	-	-	-	-	-	-	3	-
11	3	-	-	15	-	-	-	-	-	-	-	-
13	-	-	3	4	2	-	-	-	-	-	1	-
17	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	1	-	-	13	11	-
20	-	-	-	-	-	-	19	-	-	-	1	-
21	-	-	-	-	-	-	7	-	-	-	13	-
22	-	-	-	-	3	-	-	-	-	-	17	-
23	-	-	-	-	-	-	-	-	3	3	2	2
24	-	-	-	-	-	-	-	-	-	-	16	16
25	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	1	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	2	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	3	-	-	-	-	-
31	-	-	-	-	-	-	-	-	13	14	3	5
32	-	-	-	-	-	-	-	-	-	-	3	4
34	-	-	-	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	4	-	-	-	-	-
36	-	-	-	-	-	-	12	-	-	-	1	-
37	-	-	-	-	-	-	28	-	-	-	3	-
38	-	-	-	-	-	-	-	-	-	-	-	-
39	3	-	-	-	-	2	-	3	-	-	9	-
40	2	-	-	2	-	-	-	1	-	20	35	-
41	-	-	1	-	1	-	-	-	-	-	-	-
42	-	-	-	1	-	-	-	-	-	-	1	-
43	-	-	-	3	1	-	-	-	-	-	-	-
44	-	-	-	2	-	-	2	-	-	-	-	-
45	1	-	-	5	-	-	1	-	-	-	-	-
46	4	-	5	5	-	-	-	-	-	-	1	-
47	-	-	-	2	-	-	-	-	-	-	-	-
	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH
Sum:	36	2	33	99	18	2	90	7	24	83	133	29

Voxels of interest of the LORETA-based statistical nonparametric maps during emotional positive (left panel) and negative (right panel) words in the three microstates #4, #7, and #9. The number of

voxels for each Brodmann Area (BA#, first column) is listed separately for the left (LH) and for the right hemisphere (RH).

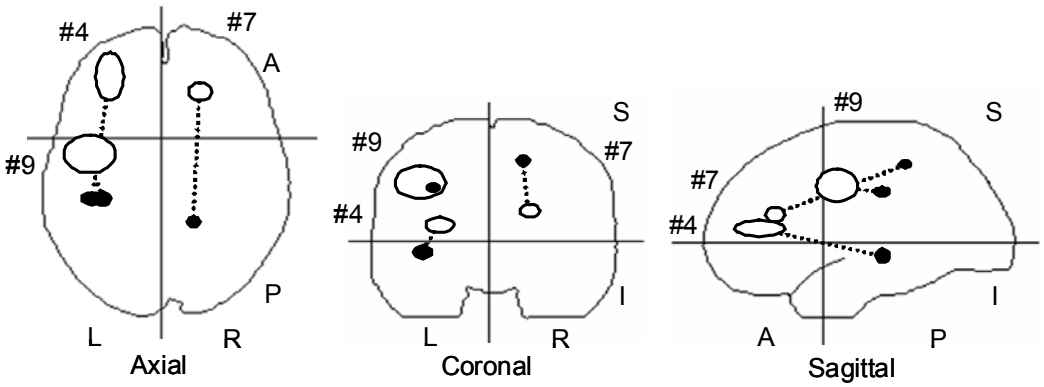

Figure 7. 95% confidence areas of the mean locations of the voxels of interest for the emotional positive (open ellipse) and negative (filled ellipse) words in the three microstates #4, #7, and #9 (for the same microstate connected by dotted lines). Display in SPM 'glass brain' space. The labels of the microstates are displayed close to their corresponding open ellipse. L/R = left/right, A/P = anterior/posterior, S/I = superior/inferior.

Table 2. Brodmann Areas during the three microstates for emotional positive and negative words.

	Emotional Positive Words						Emotional Negative Words					
Microstate:	#4		#7		#9		#4		#7		#9	
	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH
sup frontal	10	-	10	8,10,11	-	-	-	-	-	-	-	-
med frontal	10	-	10	8,9,10,11	6	-	-	-	-	-	-	-
inf frontal	10	-	10	9	-	-	-	-	-	-	-	-
sup temporal	-	-	-	-	-	-	-	-	-	-	22	-
med temporal	-	-	-	-	-	-	37	-	-	19	21,22	-
inf temporal	-	-	-	-	-	-	20,37	-	-	-	-	-
fusiform	-	-	-	-	-	-	20,36,37	-	-	-	-	-
parahippo	-	-	-	-	-	-	36,37	-	-	-	-	-
precentral	-	-	-	9	6	-	-	-	-	-	-	-
postcentral	-	-	-	-	-	-	-	-	-	40,7	-	-
paracentral	-	-	-	-	-	-	-	-	31	31	-	-
sup parietal	-	-	-	-	-	-	-	-	-	7	-	-
inf parietal	-	-	-	-	-	-	-	-	-	40	40	-
precuneus	-	-	-	-	-	-	-	-	-	19,31,7	19	-
cuneus	-	-	-	-	-	-	-	-	-	19	-	-
cingulum	-	-	-	-	-	-	-	-	31	31	24	24
sup occipital	-	-	-	-	-	-	-	-	-	19	-	-
med occipital	-	-	-	-	-	-	-	-	-	19	-	-
supramarginal	-	-	-	-	-	-	-	-	-	-	40	-

Brodmann Areas (BAs) of interest of the LORETA-based statistical nonparametric maps during emotional positive (left panel) and emotional negative (right panel) words in the three microstates #4, #7, and #9. Numbers indicate the BAs of interest (i.e., containing more than 10 activated voxels) listed by brain regions (first column), and listed separately for the left (LH) and the right hemisphere (RH).

4. Conclusion

The present study on brain electric data investigated the brain electric mechanisms of valence evaluation during reading. The results showed that the extraction of valence (a) started as early as 90 ms after onset of word display; (b) occurred in three emotion-sensitive, valence-dependent microstates, i.e. in three temporarily separated, brief epochs of information processing; and (c) incorporated the distinction of valence in these three microstates with different localization patterns, but (d) with the striking communality across the three microstates that neural activity after positive emotional words was localized in more anterior regions compared to negative emotional words.

The high temporal resolution offered by brain electric data reveals the development of valence-dependent activity in the millisecond range. The applied microstate analysis identified 14 microstates, i.e. 14 steps of information processing during the 450 ms of word presentation. The typical two major ERP components of visual paradigms with strong potential gradients over posterior brain areas ("P1" and "N1", [e.g., Koenig & Lehmann, 1996; Vitacco et al., 2002]) were observed in the present data, as microstates #4 (90-122 ms) and #6 (146-178 ms), validating the applied segmentation analysis. The emotional content of the utilized stimulus material was also validated: after the ERP recording session, subjects rated the emotional valence of the positive and negative words as significantly different.

Three of the identified 14 microstates incorporated the distinction between positive and negative valence. The effects exerted on brain electric activity by the emotional valence of the words appeared as early as 90 ms after stimulus onset, in microstate #4. Although the assumption is widespread that emotional stimuli are evaluated quickly, only quite recently EEG/EMG researchers (except for one earlier study by [Begleiter et al., 1979]) have focused their attention on 'early' brain electric components, and indeed, demonstrated that emotional information is extracted in the range of 100 ms after stimulus onset [e.g., Esslen et al., 2004; Ortigue et al., 2004; Pizzagalli et al., 2002; Pourtois et al., 2004; Skrandies, 1998; Skrandies & Chiu, 2003]. The observed early differences of brain activity suggest automatic, pre-attentive, non-conscious processing while subjects perceived emotional positive and negative stimuli. This agrees with the growing consensus that emotional perception may occur without conscious awareness [e.g., Bernat et al., 2001; Morris et al., 1998]. Most of these studies used faces or pictures as stimulus material, because pictorial stimuli are assumed to be biologically more suited to produce automatic reactions. The present study demonstrated a comparable effect with emotional words (i.e., linguistic stimuli) - one of the primary sources from which humans derive information, and one of the most important carriers of emotional meaning. Besides the temporal aspect of neural organization, the spatial organization of the neural networks that implement positive and negative emotions was a major focus of this study. The present data support the view that negative emotions activate more widespread networks than positive emotions. It has been proposed that the greater activation during the evaluation of negative stimuli represents a survival mechanism: evaluating negative stimuli might be more critical than evaluating positive stimuli [Fossati et al., 2004].

The present study found a bilateral activation in BAs 6, 8, 9, 10, and 11 during the three valence-dependent microstates when processing positive emotional words. In agreement with our ERP results, two fMRI studies [Fossati et al., 2004; Maratos et al., 2001] showed an increase of activity in prefrontal areas after visual presentation of positive words compared to

negative words. In another fMRI study that utilized acoustically presented words as stimuli [Maddock et al., 2003], the contrast between positive and neutral words showed an increase of activity in the frontal pole. Two other studies showed similar frontal and prefrontal activation after positive emotion compared to negative emotion, in one case utilizing pictorial stimuli in a PET study [Paradiso et al., 1999] and in the second case utilizing retrieval of memories as inductor of emotional states [Markowitsch et al., 2003] in an fMRI study. Finally, a recent fMRI study that used pictorial stimuli as stimulus material [Dolcos et al., 2004] found an increase of activity after positive emotions (compared with negative emotions) in the dorsolateral prefrontal cortex; an increase of activity due to negative words (compared to positive words) was found in the ventrolateral prefrontal cortex.

In the present study we found an activation of temporal areas (BAs 19, 20, 21, 22, 36, 37), parietal (BAs 7, 31, 40), and occipital (BA 19) after negative compared to positive emotional words. In the PET study discussed above [Paradiso et al., 1999], negative pictures compared to positive pictures activated in addition to subcortical areas (amygdala and cerebellum) areas in the primary and associative visual cortex. Very similar results were described in three other studies [Geday et al., 2003; Lane et al., 1997b; Taylor et al., 2000] that also used pictorial stimuli. In an fMRI study that was discussed above [Maratos et al., 2001] the contrast negative minus positive words produced an increase in parietal, temporal and occipital areas. Parietal activation due to the presentation of negative emotions was found in an fMRI study with acoustically presented words [Maddock & Buonocore, 1997].

In sum, all these studies that used very different designs, different stimulus materials, different recording, analysis and statistics methods, different tasks, etc., reached partial agreement about the cortical brain regions that are involved in the implementation of positive and negative emotions. The blood flow-based results reviewed above support our intracerebral ERP results even though there appears to be no simple direct correspondence between hemodynamic activity and electric activity [e.g. Brazdil et al., 2005; Gamma et al., 2004].

Nevertheless, we wish to put this huge amount of BA results into a more global perspective. Similar to several other recent publications that were reviewed in Introduction, the present results (1) did not support the 'valence hypothesis of hemispheric specialization' and (2) did not support the 'right hemispheric dominance model'. In microstates #4 and #9, positive as well as negative emotional words predominantly activated left hemispheric regions, whereas in microstate #7, right hemispheric regions predominated for both valences. In terms of laterality, one might argue that in our design, the presentation of the emotion-laden material as words must have preferentially concerned the language-dominant left hemisphere, and therefore could have outweighed or biased any hemispheric differences that might occur in response to the valence of a stimulus. This would mean that valence distinction could be executed by different brain areas, depending on the type of information and on input modality.

The very striking communality of valence incorporation across the three steps of valence-sensitive microstates was organized along the anterior-posterior brain axis: positive emotions activated repeatedly anterior brain areas (especially prefrontal areas), whereas negative emotions are localized in more posterior brain areas (temporal, parietal, and occipital areas). In regard to this unexpectedly clear result, the literature has little to offer. To our knowledge, no publication since the beginning of imaging studies has directly discussed a global anterior-posterior spatial organization of brain activity for valence distinction, although some studies

over the last years did report results that, in our reading, are in agreement with the present findings. Why such anterior-posterior distinctions did not receive explicit attention in the papers' discussions might be understandable in the light of the detailed voxel-by-voxel and Brodmann Area results that apparently discouraged a wider view, beyond a tentative and conditional agreement or disagreement with the popular 'valence hypothesis of hemispheric specialization' and 'right hemispheric dominance model'.

Results of anterior-posterior spatial organization for valence were published in the last years that agreed with our present results [Fossati et al., 2004; Geday et al., 2003; Lane et al., 1997a; Maddock et al., 2003; Maratos et al., 2001; Paradiso et al., 1999; Pizzagalli et al., 1999; Pizzagalli et al., 2003]. However, in none of these papers, the global issue of more anterior location for positive and more posterior location for negative emotion processing was directly discussed. The above quotations are based on our overview of the findings described in the papers' result sections, not on their discussion or summary statements.

On the other hand, the hypothesis of an anterior-posterior valence organization of brain activity is not new. About 30 years ago, when global hypotheses about emotion-associated brain activity were in the forefront, on the basis of brain lesions in the left hemisphere an anterior-posterior model of valence incorporation was proposed [Benson & Geschwind, 1975; Brown, 1975] and was hypothesized to apply also to the right hemisphere [Code, 1986], but these proposals were not followed up.

The valence-dependent anterior-posterior organization of brain activity in the present results could conceivably be related to higher visual imaginabilty of emotional negative than positive words. This is not the case, because the stimulus words in the two classes (positive and negative valence) were equalized for imagery. The only characteristic that showed differences between the classes in our results was 'activity': positive words were rated as more active than negative words. This agrees with the fact that, the 'valence' correlated with 'activity' in Osgood's listing [Osgood, 1975]: our calculation showed $r=0.338$, $df=618$, $P<0.0001$, i.e. more positive valence was associated with higher activity. This suggests that activity and positive valence may be inextricable in normal psychology.

Taken together, our results invite the speculation that positive emotions are incorporated in more anterior brain areas that are generally concerned with active decision and output functions, because positive emotions are intrinsically associated with higher activity loading, whereas negative emotions are incorporated in more posterior brain areas that are generally concerned with (passive) input and analysis functions, because negative emotions are intrinsically associated with lesser activity loading. Although there is this strong relation between the characteristic of 'activity' and positive emotional load of words, one should attempt to tease apart the suspected interaction in future experiments by controlling for 'activity' even though this will strongly restrict the possible word list.

In sum, the present results reveal a striking difference in the anterior-posterior organization of brain activity during the processing of the emotional valence of word stimuli. Depending on the microstate in which there was a significant valence-specific differentiation in brain processing, both positive and negative emotional words were processed predominantly either in the left or in the right hemisphere. But in all three microstates of valence-specific brain processing, positive words activated more anterior brain areas as compared to negative words.

Acknowledgements

L.R.R.G. and P.L.F. were partially supported by grant #67 08 06 from the Institut für Grenzgebiete der Psychologie und Psychohygiene, Freiburg i. Br., Germany.

References

Aftanas, L.I., Varlamov, A.A., Pavlov, S.V., Makhnev, V.P. & Reva, N.V. (2001). Affective picture processing: Event-related synchronization within individually defined human theta band is modulated by valence dimension. *Neuroscience Letters*, **303**, 115-118.

Begleiter, H., Porjesz, B. & Garozzo, R. Visual evoked potentials and affective ratings of semantic stimuli. In: Begleiter, H. (ed). *Evoked Brain Potentials and Behavior*. New York: Plenum Press; 1979; 127-141.

Benson, D.G. & Geschwind, N. Psychiatric conditions associated with focal lesions of the central nervous system. In: Reiser, M.F. (ed). *American Handbook of Psychiatry Vol. 4: Organic Disorders and Psychosomatic Medicine*. New York: Basic Books; 1975.

Bernat, E., Bunce, S. & Shevrin, H. (2001). Event-related brain potentials differentiate positive and negative mood adjectives during both supraliminal and subliminal visual processing. *International Journal of Psychophysiology*, **42**, 11-34.

Borod, J.C., Andelman, F., Obler, L.K., Tweedy, J.R. & Welkowitz, J. (1992). Right hemisphere specialization for the identification of emotional words and sentences: Evidence from stroke patients. *Neuropsychologia*, **30**, 827-844.

Brandeis, D., Lehmann, D., Michel, C.M. & Mingrone, W. (1995). Mapping event-related brain potential microstates to sentence endings. *Brain Topography*, **8**, 145-159.

Brazdil, M., Dobsik, M., Mikl, M., Hlustik, P., Daniel, P., Pazourkova, M., Krupa, P. & Rektor, I. (2005). Combined event-related fMRI and intracerebral ERP study of an auditory oddball task. *Neuroimage*, **26**, 285-93.

Brown, J. The neural organization of language: Aphasia and neuropsychiatry. In: Reiser, M.F. (ed). *American Handbook of Psychiatry Vol. 4: Organic Disorders and Psychosomatic Medicine*. New York: Basic Books; 1975.

Canli, T., Desmond, J.E., Zhao, Z., Glover, G. & Gabrieli, J.D. (1998). Hemispheric asymmetry for emotional stimuli detected with fMRI. *NeuroReport*, **9**, 3233-3239.

Carota, A., Rossetti, A.O., Karapanayiotides, T. & Bogousslavsky, J. (2001). Catastrophic reaction in acute stroke: A reflex behavior in aphasic patients. *Neurology*, **57**, 1902-1905.

Cato, M.A., Crosson, B., Gökçay, D., Soltysik, D., Wierenga, C., Gopinath, K., Himes, N., Belanger, H., Bauer, R.M., Fischler, I.S., Gonzalez-Rothi, L. & Briggs, R.W. (2004). Processing words with emotional connotation: An fMRI study of time course and laterality in rostral frontal and retrosplenial cortices. *Journal of Cognitive Neuroscience*, **16**, 167-177.

Code, D. (1986). Catastrophic reaction and anosognosia in anterior-posterior and left-right models of the cerebral control of emotion. *Psychological Research*, **48**, 53-55.

Damasio, A.R. *The Feeling of What Happens: Body and Emotion in the Making of Consciousness*. New York: Harcourt Brace; 1999.

Davidson, R.J., Ekman, P., Saron, C.D., Senulis, J.A. & Friesen, W.V. (1990). Approach-withdrawal and cerebral asymmetry: Emotional expression and brain physiology I. *Journal of Personality & Social Psychology*, **58**, 330-341.

Dickson, J., Drury, H. & Van Essen, D.C. (2001). 'The surface management system' (SuMS) database: A surface-based database to aid cortical surface reconstruction, visualization and analysis. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences*, **356**, 1277-1292.

Dolcos, F., LaBar, K.S. & Cabeza, R. (2004). Dissociable effects of arousal and valence on prefrontal activity indexing emotional evaluation and subsequent memory: An event-related fMRI study. *NeuroImage*, **23**, 64-74.

Esslen, M. *Brain mapping funktioneller Hirnzustände beim Lesen emotional besetzter Wörter*, Philosophische Fakultät I. Zürich, Switzerland: Universität Zürich; 1997.

Esslen, M., Pascual-Marqui, R.D., Hell, D., Kochi, K. & Lehmann, D. (2004). Brain areas and time course of emotional processing. *NeuroImage*, **21**, 1189-1203.

Fender, D.H. Source localisation of brain electrical activity. In Gevins, A.S. & Remond, A. (eds). *Handbook of Electroencephalography and Clinical Neurophysiology*, *Vol 1*. Amsterdam: Elsevier; 1987; 355-399.

Fossati, P., Hevenor, S.J., Graham, S.J., Grady, C., Keightley, M.L., Craik, F. & Mayberg, H. (2003). In search of the emotional self: An fMRI study using positive and negative emotional words. *American Journal of Psychiatry*, **160**, 1938-1945.

Fossati, P., Hevenor, S.J., Lepage, M., Graham, S.J., Grady, C., Keightley, M.L., Craik, F. & Mayberg, H. (2004). Distributed self in episodic memory: Neural correlates of successful retrieval of self-encoded positive and negative personality traits. *NeuroImage*, **22**, 1596-1604.

Gainotti, G. (1972). *Emotional behavior and hemispheric side of the lesion. Cortex*, **8**, 41-55.

Gamma, A., Lehmann, D., Frei, E., Iwata, K., Pascual-Marqui, R.D. & Vollenweider, F.X. (2004). Comparison of simultanously recorded [H215O]-Positron Emission Tomography (PET) and Low Resolution Brain Electromagnetic Tomography (LORETA) during cognitive and pharmacological activation. *Human Brain Mapping*, **22**, 83–96.

Geday, J., Gjedde, A., Boldsen, A.-S. & Kupers, R. (2003). Emotional valence modulates activity in the posterior fusiform gyrus and inferior medial prefrontal cortex in social perception. *NeuroImage*, **18**, 675-684.

Graham, R. & Cabeza, R. (2001). Event-related potentials of recognizing happy and neutral faces. *NeuroReport*, **12**, 245-248.

Koenig, T., Kochi, K. & Lehmann, D. (1998). Event-related electric microstates of the brain differ between words with visual and abstract meaning. *Electroencephalography & Clinical Neurophysiololgy*, **106**, 535-546.

Koenig, T. & Lehmann, D. (1996). Microstates in language-related brain potential maps show noun-verb differences. *Brain & Language*, **53**, 169-182.

Lane, R.D., Reiman, E.M., Ahern, G.L., Schwartz, G.E. & Davidson, R.J. (1997a). Neuroanatomical correlates of happiness, sadness, and disgust. *American Journal of Psychiatry*, **154**, 926-933.

Lane, R.D., Reiman, E.M., Bradley, M.M., Lang, P.J., Ahern, G.L., Davidson, R.J. & Schwartz, G.E. (1997b). Neuroanatomical correlates of pleasant and unpleasant emotion. *Neuropsychologia*, **35**, 1437-1444.

Lehmann, D. Principles of spatial analysis. In: Gevins, A. & Remond, A. (eds). *Handbook of Electroencephalography and Clinical Neurophysiology, Vol. 1: Methods of Analysis of Brain Electrical and Magnetic Signals*. Elsevier: Amsterdam; 1987; 309-354.

Lehmann, D. & Skrandies, W. (1980). Reference-free identification of components of checkerboard-evoked multichannel potential fields. *Electroencephalography & Clinical Neurophysiology*, **48**, 609-621.

Lehmann, D., Strik, W.K., Henggeler, B., Koenig, T. & Koukkou, M. (1998). Brain electric microstates and momentary conscious mind states as building blocks of spontaneous thinking: I. Visual imagery and abstract thoughts. *International Journal of Psychophysiology*, **29**, 1-11.

Maddock, R.J. & Buonocore, M.H. (1997). Activation of left posterior cingulate gyrus by the auditory presentation of threat-related words: An fMRI study. *Psychiatry Research: Neuroimaging*, **75**, 1-14.

Maddock, R.J., Garrett, A.S. & Buonocore, M.H. (2003). Posterior cingulate cortex activation by emotional words: fMRI evidence from a valence decision task. *Human Brain Mapping*, **18**, 30-41.

Maratos, E.J., Dolan, R.J., Morris, J.S., Henson RN, Rugg MD. Neural activity associated with episodic memory for emotional context. *Neuropsychologia* 2001; **39**:910-920.

Markowitsch, H.J., Vandekerckhovel, M.M., Lanfermann, H. & Russ, M. (2003). Engagement of lateral and medial prefrontal areas in the ecphory of sad and happy atutobiographical memories. *Cortex*, **39**, 643-665.

Michel, C.M., Murray, M.M., Lantz, G., Gonzalez, S., Spinelli, L. & Grave de Peralta, R. (2004). EEG source imaging. *Clinical Neurophysiology*, **114**, 2195-2222.

Morris, J.S., Öhman, A. & Dolan, R.J. (1998). Conscious and unconscious emotional learning in the human amygdala. *Nature*, **393**, 467-470.

Nichols, T.E. & Holmes, A.P. (2002). Nonparametric permutation tests for functional neuroimaging: A primer with examples. *Human Brain Mapping*, **15**, 1-25.

Nuwer, M.R., Comi, G., Emerson, R., Fuglsang-Frederiksen, A., Guerit, J.-M., Hinrichs, H., Ikeda, A., Luccas, F.J.C. & Rappelsburger, P. (1998). IFCN standards for digital recording of clinical EEG. *Electroencephalography & Clinical Neurophysiology*, **106**, 259-261.

Ortigue, S., Michel, C.M., Murray, M.M., Mohr, C., Carbonnel, S. & Landis, T. (2004). Electrical neuroimaging reveals early generator modulation to emotional words. *NeuroImage*, **21**, 1242-1251.

Osgood, C.E. (1952). The nature and measurements of meaning. *Psychological Bulletin*, **49**, 197-237.

Osgood, C.E. *Cross-Cultural Universals of Affective Meaning*. Urbana, Ill.: University of Illinois Press; 1975.

Paradiso, S., Johnson, D.L., Andreasen, N.C., O'Leary, D.S., Leonard Watkins, G., Boles Ponto, L.L. & Hichwa, R.D. (1999). Cerebral blood flow changes associated with attribution of emotional valence to pleasant, unpleasant, and neutral visual stimuli in a PET study of normal subjects. *American Journal of Psychiatry*, **156**, 1618-1629.

Pascual-Marqui, R.D., Lehmann, D., Koenig, T., Kochi, K., Merlo, M.C.G., Hell, D. & Koukkou, M. (1999). Functional imaging in acute, neuroleptic-naive, first-episode, productive schizophrenia. *Psychiatry Research: Neuroimaging*, **90**, 169-179.

Pascual-Marqui, R.D., Michel, C.M. & Lehmann, D. (1994). Low resolution electromagnetic tomography: A new method for localizing electrical activity in the brain. *International Journal of Psychophysiology*, **7**, 49-65.

Pascual-Marqui, R.D., Michel, C.M. & Lehmann, D. (1995). Segmentation of brain electric activity into microstates: Model estimation and validation. *IEEE Transactions on Biomedical Engineering*, **42**, 658-665.

Pitman, E.J.G. (1937). Significance tests which may be applied to samples from any populations. *Journal of the Royal Statistical Society*, **4**, 119-130.

Pizzagalli, D., Koenig, T., Regard, M. & Lehmann, D. (1999). Affective attitudes to face images associated with intracerebral EEG source location before face viewing. *Cognitive Brain Research*, **7**, 371-377.

Pizzagalli, D., Lehmann, D., Hendrick, A.M., Regard, M., Pascual-Marqui, R.D. & Davidson, R.J. (2002). Affective judgements of faces modulate early activity (~160 ms) within the fusiform gyri. *NeuroImage*, **16**, 663-677.

Pizzagalli, D.A., Greischar, L.L. & Davidson, R.J. (2003). Spatio-temporal dynamics of brain mechanisms in aversive classical conditioning: High-density event-related potential and brain electrical tomography analyses. *Neuropsychologia*, **41**, 184-194.

Pourtois, G., Grandjean, D., Sander, D. & Vuilleumier, P. (2004). Electrophysiological correlates of rapid spatial orienting towards fearful faces. *Cerebral Cortex*, **14**, 619-633.

Rosengren I. *Frequenzwörterbuch der Deutschen Zeitungssprache*. Köpenhamn: Villadsen & Christensen; 1977.

Sander, K., Roth, P. & Scheich, H. (2003). Left-lateralized fMRI activation in the temporal lobe of high repressive women during the identification of sad prosodies. *Cognitive Brain Research*, **16**, 441-456.

Schupp, H.T., Junghöfer, M., Weike, A.I. & Hamm, A.O. (2004). The selective processing of briefly presented affective pictures: An ERP analysis. *Psychophysiology*, **41**, 441-449.

Skrandies, W. (1998). Evoked potential correlates of semantic meaning. A brain mapping study. *Cognitive Brain Research*, **6**, 173-183.

Skrandies, W. & Chiu, M.J. (2003). Dimensions of affective semantic meaning - behavioral and evoked potential correlates in chinese subjects. *Neuroscience Letters*, **341**, 45-48.

Spence, S., Shapiro, D. & Zaidel, E. (1996). The role of the right hemisphere in the physiological and cognitive components of emotional processing. *Psychophysiology*, **33**, 112-122.

Strik, W.K., Fallgatter, A.J., Brandeis, D. & Pascual-Marqui, R.D. (1998). Three-dimensional tomography of event related potential during response inhibition: Evidence for phasic frontal lobe activation. *Electroencephalography & Clinical Neurophysiology*, **109**, 406-413.

Sutton, S.K., Davidson, R.J., Donzella, B., Irwin, W. & Dottl, D.A. (1997). Manipulating affective state using extended picture presentations. *Psychophysiology*, **34**, 217-226.

Talairach, J. & Tournoux, P. *Co-Planar Stereotaxic Atlas of the Human Brain*. Stuttgart: Thieme; 1988.

Taylor, S.F., Liberzon, I. & Koeppe, R.A. (2000). The effect of graded aversive stimuli on limbic and visual activation. *Neuropsychologia*, **38**, 1415-1425.

Terzian, H. & Ceccotto, C. (1959). Su un nuovo metodo per la determinazione e lo studio della dominanza emisferica. *Giornale di Psichiatria e Neuropatologia*, **87**, 889-924.

Towle, V.L., Bolanos, J., Suarez, D., Tan, K., Grzeszczuk, R., Levin, D.N., Cakmun, R., Frank, S.A., & Spire, J.P. (1993). The spatial location of EEG electrodes: Locating the best-fitting sphere relative to cortical anatomy. *Electroencephology & Clinical Neurophysiology*, **86**, 1-6.

Vitacco, D., Brandeis, D., Pascual-Marqui, R.D. & Martin, E. (2002). Correspondence of event-related potential tomography and functional magnetic resonance imaging during language processing. *Human Brain Mapping*, **17**, 4-12.

Wager, T.D., Luan Phan, K., Liberzon, I. & Taylor, S.F. (2003). Valence, gender, and lateralization of functional brain anatomy in emotion: A meta-analysis of findings from neuroimaging. *NeuroImage*, **19**, 513-531.